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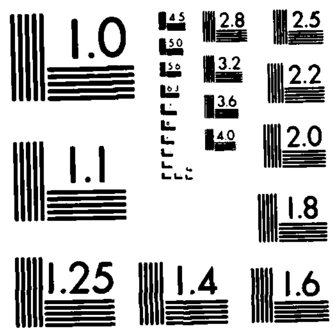

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THE ADJUSTMENT OF EMPLOYMENT TO TECHNICAL CHANGE IN THE STEEL AND AUTO INDUSTRIES

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INTRODUCTION

Technical change, for all the good it does for society, is not an unmixed blessing. Though it leads to the development of useful new products and new production processes, it may impose hardships on those who use old, and no longer efficient, methods or produce products that are no longer wanted. Workers can gain as their industries remain competitive with foreign producers of similar products. As consumers, they also gain from increases in productivity; they are able to buy things at lower prices. But if workers cannot adapt to new production methods and lose their jobs as a result, they can end up as net losers.

~~In this paper, we~~ present estimates of what effect technical change had on labor demand from 1958 to 1977 in two important U.S. industries --steel and autos. Both of these industries have, over the period studied, experienced technological innovation; new methods of production have been developed and introduced. At the same time, their employment experience has been mixed. Employment grew over the time period in the auto industry, but fell in the steel industry. This kind of mixed pattern makes it difficult to relate technical change and employment. Technical change might have decreased employment by displacing workers with new machines and equipment, or it might have increased employment by helping to keep these industries competitive in world markets.

We measure the first effect, the direct substitution of machines for people in production as the percentage change in labor demand when technology increases by one unit. It is a "partial" effect in the sense that other variables that might affect employment are being held constant. There is also an indirect effect: Technical change lowers the prices of industry output, which, holding other things constant, leads to greater output. This, in turn, raises the demand for labor. Summing the partial and indirect effects gives a more complete accounting of the total effect of new technologies.

To model the effects of technical change, we use a transcendental logarithmic (translog) cost function. We focus on two methodological issues. The first is to distinguish the effects of technical change from the effects of scale economies. Though scale economies have not been totally ignored in the literature, we show why their measurement is particularly important in time-series applications where input adjustment is usually less than instantaneous.

The second issue is how "technology" can best be summarized in a single time series variable. Typically, a time trend is used to represent smooth, undifferentiated changes in technology. To the extent that changes in technology do unfold gradually, the time trend's simplicity is an important attribute. On the other hand, if technical change occurs in discrete "jumps," it may cause sudden shifts in the demand for inputs like labor. We therefore constructed direct measures of "new process innovation" in each industry. These measures were designed to capture the timing with which new types of machinery or equipment have been adopted. We then compared the results of estimation using the two alternative measures of technology.

THE DEFINITION OF TECHNICAL CHANGE

Technical change is related to both new process innovation and productivity growth. For this study, we adopt the economist's standard definition of technical change: a shift (or rotation) in an isoquant so that, at constant factor prices, different factor amounts are used. The definition of process innovation, on the other hand, is less formal. It refers to changes in techniques such as the adoption of the basic-oxygen furnace and continuous casting in steel and "Detroit automation" and industrial robots in the auto industry. The adoption of a "new" process is defined to be a technical change, however, only when it lowers cost at fixed factor prices.

Productivity is defined as output per unit of input. It is sometimes attributed to a single factor--for example, labor--but in this paper, we consider all inputs together and measure total factor productivity. Growth in productivity can come from two sources: technical change and scale economies.

The degree to which scale economies are important depends upon the relationship between changes in industry cost and changes in output. It is often assumed that, for an industry in long-run equilibrium, returns to scale are constant (CRS), which means that cost and output change proportionately. If the CRS assumption is correct, scale does not contribute to productivity growth and the rates of productivity growth and technical change are equivalent. We will show that whether or not the assumption of CRS should be made depends crucially on the particular situation being studied.

RELATED WORK AND THE ISSUE OF RETURNS TO SCALE

Many previous studies have assumed that cost is characterized by a translog function in which all inputs are perfectly variable, i.e., inputs are assumed to adjust to their optimal levels instantaneously. Translog models have been used in both time-series* and cross-section** studies, and their use has become standard in studying technical change and productivity growth.

The cost model approach, regardless of the type of application, does seem to distinguish adequately between factor substitution and technical change. That is, we can tell if we are observing an inward shift in the position of the isoquant, with fixed relative factor

* Examples of studies that use industry time-series data are Berndt and Khaled [5], Jorgenson and Fraumeni [17], Mohr [23], Moroney and Toevs [25], Moroney and Trapani [24], and Wills [33].
** Examples of cross-section studies, including pooled samples (cross-section time series) are Gollop and Roberts [14, 15]; Christensen and Greene [11]; Stephenson [28]; Friedlander, Spady, and Chiang [14]; and Karlson [19]; the latter paper is a model of the integrated steel industry.

prices, or a movement along the same isoquant in response to changing relative factor prices.

In contrast, the issue of scale economies makes the distinction between cross-section studies and time-series studies an important one. In cross-section studies, CRS is not assumed; instead, returns to scale are calculated from the parameters of the estimated econometric model. Typically, these studies find returns to scale are nearly constant (i.e., the scale elasticity is close to one).

The degree of scale economies relates directly to the shape of the average cost curve. The finding of constant returns, using a cross section of firms, therefore implies that firms producing twice the output of other firms in the industry do so with twice as many inputs (and equivalently, costs go up proportionately with output).

Though the finding of CRS may be valid in cross-section analysis, assuming it in time-series estimation of an industry cost model is more questionable. As firms within an industry respond to changes in output, the corresponding changes in their use of inputs will depend upon the costs of adjustment associated with each. For those inputs whose adjustment costs are low (e.g., materials) we would expect that changes in demand are proportional to changes in output. For other inputs (e.g., capital), adjustment costs are likely to be high, and so we might expect these inputs to adjust less than proportionately with output.

This tendency to partial adjustment of inputs whose adjustment costs are high is reinforced by the cyclical nature of output changes. To the extent that output changes are transitory, firms will tend not to adjust those inputs with high adjustment costs; they will make major changes only in response to output changes that are expected to be long lasting. This phenomenon is often called "factor hoarding"; it refers to a firm or industry holding on to certain factor inputs in the short run even when output falls because it will be too costly to obtain equivalent inputs later when output recovers. An analogous situation holds for output increases; the firm refrains from obtaining certain "expensive" inputs until it is sure that output will remain high.

Because of this, time-series estimates of the scale elasticity must be interpreted with care. As in most translog studies, our model assumes that all inputs are perfectly variable. A scale elasticity less than one, indicating increasing returns to scale, could result, not only from the existence of true scale economies, but from the fact that we use annual data that may not reflect true, long-run adjustment. The presence of quasi-fixed factors, however, will lead to findings that conflict with the long-run equilibrium assumptions. While the model cannot choose between scale economies and fixed inputs as competing explanations, the approach we take allows us to identify the individual inputs that do not adjust proportionately with output. We interpret a finding that capital, for example, does not adjust proportionately as implying that capital is a quasi-fixed input. The issue is not just an econometric fine point. Since we are interested in determining the "pure" effects of technical change on input demand, it is important to separate these effects from scale effects. To the extent that certain factor inputs do not adjust with output, and CRS is assumed, computed rates of technical change will be overstated.

THE COST MODEL AND INPUT DEMAND

The cost function approach to modeling technical change begins with a cost function for each industry

$$C = F(P, Q, T) \tag{1}$$

where

P = vector of (exogenous) input prices

Q = level of real output in the industry

T = measure of technology in the industry.

To derive the relationship between productivity growth, scale economies, and technical change, we begin with the change in cost over time. The components of the rate of growth of total cost are obtained by differentiating the logarithmic form of equation (1) with respect to time (t),*

$$\frac{d\ln C}{dt} = \sum_{i=1}^{n} \frac{\partial \ln C}{\partial \ln P_i} \frac{d\ln P_i}{dt} + \frac{\partial \ln C}{\partial \ln Q} \frac{\partial \ln Q}{dt} + \frac{\partial \ln C}{\partial T} \frac{dT}{dt} .$$

Substituting V_i (the share of the ith input in cost, from Shephard's Lemma) for $\partial \ln C/\partial \ln P_i$, V_Q (returns to scale) for $\partial \ln C/\partial \ln Q$, and $-V_T$ (the negative of the rate of technical change) for $\partial \ln C/\partial T$ gives:

$$\frac{d\ln C}{dt} = \sum_{i=1}^{n} V_i \frac{d\ln P_i}{dt} + V_Q \frac{d\ln Q}{dt} - V_T \frac{dT}{dt} . \quad (2)$$

The rate of growth in cost is composed of the weighted average of the rates of growth of input prices, the scale weighted rate of growth of output, and the rate of cost reduction due to technical change.

Since total factor productivity growth (V_G) is defined as the negative of the change in average cost (with input prices held constant), we can use equation (2) and derive the following expression:

$$V_G = (1 - V_Q) \frac{d\ln Q}{dt} + V_T \frac{dT}{dt} . \quad (3)$$

If we were to assume constant returns to scale, that $V_Q = 1$, then $V_T \frac{dT}{dt}$, the rate of technical change, and V_G, become equivalent. If

* We will use T to represent technology for both the time trend and direct measures of new process innovation. The variable t will represent movements over time in all variables.

V_Q is really not equal to one, that is, returns to scale are either increasing ($V_Q < 1$) or decreasing ($V_Q > 1$), then the rate of technical change will differ from total factor productivity.

The Empirical Cost Function

We approximate equation (1) with a translog cost function:

$$\ln C = \alpha_0 + \Sigma_i \beta_i \ln P_i + \beta_Q \ln Q + \beta_T T + \frac{1}{2} \sum_{ij}\sum \gamma_{ij} \ln P_i \ln P_j + \Sigma_i \gamma_{iQ} \ln P_i \ln Q$$

$$+ \Sigma_i \gamma_{iT} (\ln P_i)(T) + \frac{1}{2} \gamma_{QQ} (\ln Q)^2 + \gamma_{QT} (\ln Q)(T) + \frac{1}{2} \gamma_{TT} T^2 . \quad (4)$$

To derive the effects of input prices, scale, and technology, we differentiate equation (4) with respect to logs of input prices and output and the measure of technology. This yields the following:

$$V_i = \beta_i + \Sigma_j \gamma_{ij} \ln P_j + \gamma_{iQ} \ln Q + \gamma_{iT} T , \quad i = 1, \ldots, n \quad (5)$$

and

$$W = V_Q \frac{d\ln Q}{dt} - V_T \frac{dT}{dt}$$

$$= [\beta_T + \Sigma_i \gamma_{ij} \ln P_i + \gamma_Q Q \ln Q + \gamma_{QT} T] \frac{d\ln Q}{dt}$$

$$- [\beta_T + \Sigma_i \gamma_{iT} \ln P_i + \gamma_{QT} \ln Q + \gamma_{TT} T] . * \quad (6)$$

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* The relationship between W and V_G is given by

$$W = \frac{d\ln Q}{dt} - V_G .$$

Equations (4), (5), and (6) made up the system to be estimated. As usual, one input share was deleted to avoid singularity of the disturbance covariance matrix. Since maximum likelihood estimation yields results that are invariant to the choice of the deleted equation, the iterative version of Zellner's "seemingly unrelated regression" model was used to derive parameter estimates. Finally, to insure linear homogeneity in prices as well as to take into account the adding up condition, the following constraints were imposed on the system:

$$\Sigma_i \beta_i = 1,$$

$$\Sigma_i \gamma_{ij} = \Sigma_i \gamma_{iQ} = \Sigma_i \gamma_{iT} = 0, \qquad \text{for } i, j = 1, \ldots, n .$$

Input Demand

One of our objectives is to derive the effects of the exogenous variables on factor input quantities* (as opposed to shares) and, in particular, on the quantity of labor. The important relationships between input demand and the exogenous variables can be derived from the cost and share equations.

* We denote input quantities by X_i, where $i = 1, \ldots, n$. This provides notational consistency with the representation of the ith share and the ith price (V_i and P_i, respectively). We will drop the subscript notation later when we focus on specific inputs like labor.

We begin with the input demand equation; in functional form, it is analogous to the input share equation (5):

$$X_i = X_i\ (P_i,\ \ldots,\ P_n,\ Q,\ T) \tag{7}$$

where the demand for X_i is a function of all input prices output and technology. Differentiating the log form of this equation with respect to time yields

$$\frac{d\ln X_i}{dt} = \sum_{j=1}^{n} \varepsilon_{ij} \frac{d\ln P_i}{dt} + \varepsilon_{iQ} \frac{d\ln Q}{dt} + \varepsilon_{iT} \frac{dT}{dt} \tag{8}$$

where ε_{ij} ($= \partial\ln X_i/\partial\ln P_j$) is the cross price elasticity of demand (or the own price elasticity when $i=j$); ε_{iQ} ($= \partial\ln X_i/\partial\ln Q$) is the input i - output elasticity, and ε_{iT} ($= \partial\ln X_i/\partial T$) is the input i - technology elasticity.

Equation (8) illustrates that, for example, the demand for labor will change over time as a result of (1) changes in input prices, weighted by the cross (own) price elasticities for labor; (2) changes in output, weighted by the labor-output elasticity; and (3) changes in technology, weighted by the labor-technology elasticity. The product $\varepsilon_{LT}(dT/dt)$ represents the change in labor demand arising from changes in technology. Its calculated value may be compared with the values representing changes in workers' wages, other input prices, and output in order to determine its relative importance as a source of employment change.

To derive the elasticity formula under the translog specification, we begin by rewriting the definition of the ith input's share so that the input quantity of labor is on the left-hand side, or $X_i = V_i C/P_i$. Taking logarithms and then totally differentiating the quantity of input i with respect to time yields

$$\frac{d\ln X_i}{dt} = \frac{d\ln V_i}{dt} + \frac{d\ln C}{dt} - \frac{d\ln P_i}{dt} . \tag{9}$$

The second term on the right-hand side was given in equation (2). To obtain an expression for $d\ln V_i/dt$, we differentiate the estimated equation for the ith input share (given by equation (5)) and then divide by V_i, or

$$\frac{d\ln V_i}{dt} = \frac{1}{V_i}\frac{dV_i}{dt} = \sum_{j=1}^{n} \frac{\gamma_{ij}}{V_i}\frac{d\ln P_j}{dt} + \frac{\gamma_{iQ}}{V_i}\frac{d\ln Q}{dt} + \frac{\gamma_{iT}}{V_i}\frac{dT}{dt} . \tag{10}$$

Substituting equations (2) and (10) into (9) ields:

$$\frac{d\ln X_i}{dt} = \left(\frac{\gamma_{ii}}{V_i} + V_i - 1\right)\frac{d\ln P_i}{dt} + \sum_{j\neq i}\left(\frac{\gamma_{ij}}{V_i} + V_j\right)\frac{d\ln P_j}{dt}$$

$$+ \left(\frac{\gamma_{iQ}}{V_i} + V_Q\right)\frac{d\ln Q}{dt} + \left(\frac{\gamma_{iT}}{V_i} - V_T\right)\frac{dT}{dt} . \tag{11}$$

Equation (11) provides the formulas needed to calculate the elasticities of equation (8).

DATA

For the empirical analysis we use industries defined at the 4-digit SIC level. Steel is SIC 3312 (blast furnaces and steel mills); autos is the combination of SICs 3711 (motor vehicles and car bodies) and 3714 (motor vehicle parts and accessories). The primary data sources were the Quinquennial Census of Manufactures and for intervening years, the Annual Survey of Manufactures. From these sources, we distinguish four types of inputs: production labor (L), nonproduction labor (N), capital (K), and materials. Aggregate materials have two components: energy (F) and nonenergy materials (M). To measure F, we used the value and quantity of BTU equivalents (for roughly three-digit SICs, which we then adjusted) reported by the Department of Energy. Cost and output were also obtained from the Census and Annual Survey although, in steel, we used actual tons produced as reported by the American Iron and Steel Institute.

The variables representing new process innovation required special development. For steel, we focused on three new technologies: basic oxygen furnace (BOF) and oxygen lancing in open-hearth furnaces, which are important inn the steelmaking process, and pelletization of iron ore,* which involves concentrating the iron in ores. Pelletization has made it possible to use low-grade ore in the initial iron-making process and has greatly increased the capacity of blast furnaces.** Data on the adoption of these innovations, published by the American Iron and Steel Institute, have been combined into a single index, weighted by the percentage that each is expected to reduce costs.

Technical change in the auto industry since World War II has involved substitution of machines for workers in actual production processes such as welding. To quantify the concept of automation, we measure the stock of transfer machines, the basic unit of what is known as Detroit Automation. A transfer machine performs several operations, each of which would otherwise be performed at different stations on the production line. Using data from a number of sources, including the American Machinist and the Department Commerce's Current Industrial Reports, we added up the number of transfer machines and adjusted the total to take account of increases in the value of machines over and above inflation. The adjustment was made to represent increases in the complexity and size of the individual machines. The stock is measured relative to the total auto industry capital stock.

* One other change, continuous casting, apparently is an innovation whose cost reducing properties are likely to occur in the future (see [13]).

** These furnaces reduce iron ore, converting it into pig iron, a molten iron used in steelmaking.

One other advance in auto technology, the use of robots to weld or paint car bodies and parts, or perform other menial or dangerous jobs, is only now beginning to occur in significant numbers. The impact up to this point is relatively insignificant, and so we have not included the introduction of robots in our technology measures.*

EMPIRICAL RESULTS

To describe the results of estimation, we focus on factor substitution, scale, and technical change. All inputs are handled analogously, that is, labor gets no special treatment. While the results for the other inputs are not all important, they help in demonstrating the nature of cost and production in each industry, and they serve as a useful check on the model and its assumptions.

Empirical Results--Substitution Elasticities

Own price elasticities and the elasticities of substitution between pairs of inputs are shown in table 1 for both the time trend and the direct measures of technology.** Substitution elasticities and the input-price elasticities discussed earlier are related in a simple way, namely $\sigma_{ij} = \varepsilon_{ij}/V_j$.

* One estimate of the expenditure on robots in the auto industry in 1979, "Robots Swing into the Arms Race," Iron Age, July 21, 1980, was about $15 million. This compared to a total expenditure or auto plant and equipment (from Survey of Current Business) of about $8.3 billion.
** Estimates were calculated at input share sample means also reported in table 1.

TABLE 1

OWN PRICE AND CROSS SUBSTITUTION ELASTICITIES
IN STEEL AND AUTOS, ESTIMATED WITH A TIME TREND
AND A DIRECT MEASURE OF TECHNOLOGY

Elasticity	Steel: Time trend	Steel: Direct measure	Autos: Time trend	Autos: Direct measure
ϵ_{LL}	-.30	-.26	-.17	-.47
ϵ_{NN}	-.76	-.73	-.67	-.74
ϵ_{KK}	-.10	-.07	-.16	-.53
ϵ_{FF}	-.02	-.05	-.49	-.57
ϵ_{MM}	-.16	-.12	-.08	-.18
σ_{LN}	3.22	3.90	6.15	5.11
σ_{LK}	.04	-.10	-.54	.60
σ_{LF}	-.20	-.28	1.00	-3.71
σ_{LM}	.27	.17	.01	.31
σ_{NK}	-.46	-.70	-1.14	-.63
σ_{NF}	-.56	.46	-8.30	-5.29
σ_{NM}	.55	.27	.11	.29
σ_{KF}	-.17	.04	-.29	-.86
σ_{KM}	.28	.26	.42	.73
σ_{FM}	.24	.25	.68	2.14
$\bar{V}_L$	.197		.135	
$\bar{V}_N$	.058		.038	
$\bar{V}_K$	.169		.160	
$\bar{V}_F$	.099		.007	
$\bar{V}_M$	.473		.660	

Generally, the results are similar regardless of how technology is measured. The own price elasticities are always negative, and typically, the larger the share of an input in total cost, the smaller the own elasticity, perhaps signifying that less substitution is possible for relatively more important inputs.

The cross-substitution elasticities generally show that production and nonproduction labor are highly substitutable and that nonproduction labor and capital are complementary. Materials substitute with everything else, though usually at a relatively small degree. For production labor and capital the results are mixed and depend upon the technology measure. Generally, the labor-capital substitution elasticity is small and may signify a fixed coefficient production technology in the short run (i.e., at fixed technology) between labor and capital inputs.*

Empirical Results--Scale

The estimates of the scale parameters are presented in table 2. In steel, the parameters are very similar, regardless of the technology measure used. Our discussion concentrates on the time-trend version in both industries though there are some differences arising in the regression for autos (in particular the reversal of signs for the labor and capital inputs).

* The own and cross elasticities of substitution relates directly to the stability of the cost function. For further discussion, see [21].

TABLE 2

SCALE PARAMETER ESTIMATES

Scale parameter	Steel Time trend	Steel Direct measure	Autos Time trend	Autos Direct measure
γ_{LQ}	.008 (.80)	.023 (2.12)	.014 (1.29)	-.020 (-2.31)
γ_{NQ}	-.019 (-3.91)	-.013 (-2.17)	-.009 (-1.92)	-.013 (-3.08)
γ_{KQ}	-.052 (-3.51)	-.064 (-4.45)	-.082 (-2.91)	.007 (.65)
γ_{FQ}	.007 (1.47)	-.003 (-.78)	-.001 (-.93)	.001 (1.04)
γ_{MQ}	.056 (2.27)	.057 (2.25)	.078 (2.58)	.025 (1.65)
γ_{QQ}	.012 (.11)	.038 (.23)	.093 (.48)	.018 (.22)
γ_{Qt}	.001 .63	.117 (1.17)	.012 (1.27)	.118 (2.73)
Scale elasticity				
(V_Q)	.77	.72	.84	.78

The computed scale elasticity (V_Q) shows that both industries exhibit increasing returns to scale, regardless of how technology is measured. Under the usual interpretation, the parameters used in the calculation of V_Q measure how it changes in response to changes in the exogenous variable. The positive coefficient for γ_{QT} in autos means that a change in technology (as measured by a higher proportion of transfer machines) moved the industry toward lower scale economies. In a similar manner, a negative γ_{KQ} (for all cases but the direct measure in autos) implies that increases in the price of capital moved the industry to expansion paths characterized by greater scale economies.

Because the γ_{iQ} appear in the share equations and multiply output, they may be used to identify factor inputs whose quantities move less than proportionately with output. For example, consider $\frac{\partial \ln X_i}{\partial \ln Q}$ derived earlier in equation (11):

$$\frac{\partial \ln X_i}{\partial \ln Q} = \frac{\gamma_{iQ}}{V_i} + V_Q$$

where $\frac{\gamma_{iQ}}{V_i} = \partial \ln V_i / \partial \ln Q$ (since $\partial V_i / \partial \ln Q = \gamma_{iQ}$) . The assumption of constant returns to scale means that $V_Q = 1$ and γ_{iQ} for every i must equal 0. This, in turn, means that $\partial \ln X_i / \partial \ln Q = 1$ so that all inputs must adjust proportionately with output.

A finding that $\frac{\partial \ln X_i}{\partial \ln Q} = 1$ for some inputs does not mean that returns are constant, however. If $\frac{\gamma_{iQ}}{V_i}$ and V_Q are estimated independently, they may sum to 1 even though returns are not constant. For example, when we use the time trend measure of technology for steel and autos, the $\frac{\partial \ln X_i}{\partial \ln Q}$ for production labor, fuel, and materials are close to 1, particularly when their respective γ_{iQ} are significantly positive. But the V_Q shown in table 2 are about .80, not 1. When estimated in this way, without assuming CRS, $\frac{\partial \ln X_i}{\partial \ln Q}$ is sometimes far from 1. For example, capital adjusts less than proportionately with output in both industries, giving $\partial \ln K/\partial \ln Q$ values of .47 and .33, for steel and autos, respectively.

V_Q is usually interpreted as a measure of returns to scale in the production process. It also represents the degree to which overall factor inputs move with output. To show this, it is helpful to go back to the derivation of V_Q (which is simply $\frac{\partial \ln C}{\partial \ln Q}$) from the definition of total cost, $C = \Sigma_i P_i X_i$. It follows that

$$\frac{\partial C}{\partial Q} = \Sigma_i P_i \frac{\partial X_i}{\partial Q}$$

or after some simple manipulation,

$$V_Q = \frac{\partial \ln C}{\partial \ln Q} = \Sigma_i \frac{P_i X_i}{C} \frac{\partial \ln X_i}{\partial \ln Q} = \Sigma_i V_i \varepsilon_{iQ} \text{ . *}$$

* Substituting this relationship for V_Q in the calculation for $\partial \ln X_i/\partial \ln Q$ illustrates how the degree of adjustment for input i is in some sense, a deviation away from the average adjustment for all inputs; the measure of this deviation being γ_{iQ}/V_i.

To the extent that factors that do not adjust proportionately with output are present, V_Q will be less than one. Though the presence of inputs that do move proportionately with output will move the calculated value of V_Q closer to one, it is because the capital stock changes slowly in the time trend regressions that V_Q ends up with a low value. In a similar way, the regression on the direct measure of technology for autos implies that labor adjusts more slowly than does capital, and both adjust less than proportionately with output. Thus, both industries are characterized by $V_Q < 1$, which we attribute to the presence of fixed factors, as well as any possible decreased cost associated with increased output.*

Empirical Results--Technical Change

Allowing for nonconstant returns is particularly important if the rate of technical change $V_T \frac{dT}{dt}$ and the individual technical change parameters γ_{iT} are to be estimated without bias. As we have seen, V_T and γ_{iT} are elements in the expression of $\frac{\partial \ln X_i}{\partial T}$, which we term the partial effect of technology.

* To determine the importance of scale and the presence of quasi-fixed factors, two variants of the model were also run. For steel, the assumption of CRS did not change most parameters very much, the exception, of course, being the γ_{iQ}s (assumed to be zero). Also the rate of technical change was higher (as expected). For motor vehicles, a model allowing for quasi-fixed factors was developed and estimated, but the results concerning technical change were similar to those presented here. See [21] for more details, as well as an example of an industry (aluminum) for which a large quasi-fixed capital stock did affect the estimated results for the scale elasticity and rate of technical change.

To interpret $\frac{\partial \ln X_i}{\partial T}$, we first focus on the empirical results for V_T and the γ_{iT} shown in table 3. In the time-trend regressions, the parameters γ_{Lt}, γ_{Nt}, γ_{Kt}, γ_{Ft}, and γ_{Mt} measure the effect of technical change on a factor input, since these parameters appear in all share equations as the coefficient on time (technology). Thus, γ_{Lt}, for example, measures the effect of technical change on labor's share ($\gamma_{Lt} = \partial V_L/\partial t$). If time has a negative effect on labor's share, it is considered to reflect labor-saving technical change.

Both industries have experienced strong labor-saving technical change. The estimates were statistically significant for production labor in both industries and for nonproduction labor (significant only for steel). Technical change is capital-using, although more so in steel than in autos. While there is little evidence of labor-capital substitution, holding output and time (technology) constant, technical change is labor-saving and capital-using over time. It appears that the substitution of capital for labor occurs with later vintages of capital. In other words, newer capital displaces labor more than did older capital, regardless of the short-run substitution possibilities.

There was almost no technical change in steel for the period studied while technology in autos advanced at an average of almost 1.8 percent a year. Since steel has been an industry in decline for many years, showing low rates of TFP growth, it is not surprising to find little technical change.

TABLE 3

TECHNICAL CHANGE PARAMETER ESTIMATES

Technical change Parameters	Steel: Time trend	Steel: Direct measure	Autos: Time trend	Autos: Direct measure
γ_{LT}	-.003 (-10.95)	-.128 (-12.26)	-.003 (-4.01)	.003 (.61)
γ_{NT}	-.0005 (-3.60)	-.029 (-5.49)	-.0003 (-.99)	.0008 (.47)
γ_{KT}	.003 (6.82)	.098 (8.2)	.003 (1.91)	-.022 (-3.38)
γ_{FT}	-.0002 (-1.05)	.007 (1.76)	.0002 (2.48)	.002 (5.73)
γ_{MT}	.0007 (1.28)	.066 (3.45)	-.0001 -.09)	.016 (2.65)
γ_{QT}	.001 (.63)	.117 (1.17)	.012 (1.27)	.118 (2.73)
γ_{TT}	.0009 (7.07)	.419 (2.10)	-.002 -4.04)	-.208 (-6.82)
Rate of technical change				
v_T	.002%	-.10%	1.79%	1.40%

With the direct measure, the results for steel are essentially the same.* The rate of technical change is still insignificant at -.1 percent a year on average.

For autos, the results derived when the direct measure is used are different from those derived with the time trend. While the individual parameters imply very different kinds of input biases arising from technical change: Technical change is labor-neutral, not labor-saving; capital's share decreases with new technology, which is different from previous results; strong fuel-using technical change is still evident, but now there appears to be strong material-using technical change. The value of γ_{TT} still implies that cost savings increase with new technology, but γ_{QT} is now significantly positive. This finding implies that increases in output lead to decreases in rates of technical change. Thus, in a number of ways, the results differ with the use of a direct measure of technology in autos.

Turning back to our discussion of the technology elasticity (under the time trend specification), it measures the effects of new technology (as measured by time) on the quantity of input demanded, when input prices and output are constant. Repeated below, it is:

$$\frac{\partial \ln X_i}{\partial T} = \left(\frac{\gamma_{iT}}{V_i} - V_T\right) .$$

* The coefficients under the direct measure specification can be transformed into equivalent units by multiplying by dT/dt.

This relationship implies that input use is reduced with positive rates of technical change, but this effect is increased by input-saving technical change ($\gamma_{iT} < 0$) or decreased by input-using technical change ($\gamma_{iT} > 0$). What the elasticity illustrates is that if $\gamma_{iT} = 0$, implying that there is no bias either away from or toward a particular factor, then technical change, represented by an inward shift of the isoquant at constant relative prices reduces all input use by the overall rate of technical change, V_T.

Later in the paper, we will calculate the values of the elasticity for the labor input in both industries and with both measures of technology. Here, let us illustrate the use of the elasticity focusing on the average change in labor and capital over time. Steel had virtually a zero rate of technical change. Using γ_{LT} and γ_{KT} from the regression, the (calculated) value of $\partial \ln X_L/\partial t$ is -1.72 percent on average and for $\partial \ln X_K/\partial t$, it is 1.78 percent. Autos had a mean value of $V_T \frac{dT}{dt}$ of just below 2 percent per year. Coupled with our finding of labor-saving and capital-using technical change (i.e., $\gamma_{LT} < 0$ and $\gamma_{KT} > 0$), there is relatively greater reduction in the use of labor, about -4.2 percent while capital barely increases at all, about .1 percent on average. To the extent that time represents technology, labor does get displaced by new technologies.

The Explanation of Productivity Growth

Empirical estimates of V_Q and V_T enable us to determine which component of productivity growth--i.e., the scale related component $(1 - V_Q)$ dlnQ/dt or the rate of technical change $V_T \frac{dT}{dt}$ --has contributed more to changes in productivity over time.

These two components of productivity growth for steel and autos are shown in table 4 using estimates derived from the time trend regressions. The components were estimated for three subperiods as well as for the entire time period. In steel, the estimated productivity growth for the 1959-77 period is made up almost entirely of the scale component; technical change, as we have seen, is close to zero on average. When the subperiods are calculated separately, the scale related component and the rate of technical change decrease over time. Indeed, over the 1974-77 time period, both contributed to a substantial decline in productivity, which averaged about -1.4 percent per year.

The pattern in autos is different. The rate of productivity growth averages just over 3 percent a year for the entire period. Growth was rapid in the earlier period, fell in the middle period, and rose at the end. The scale component decreased throughout whereas the rate of technical change increased throughout, attaining about a 3-1/3 percent growth rate over the last period. This occurred as the contributions arising from scale fell close to zero.

TABLE 4

CONTRIBUTIONS OF SCALE AND TECHNICAL CHANGE
TO PRODUCTIVITY GROWTH
(STEEL AND AUTOS)

Time Period	Average Rate of Productivity Growth (%)		Scale (%)		Technical Change (%)	
	Steel	Autos	Steel	Autos	Steel	Autos
1959-1977	.55	3.03	.55	1.24	.002	1.79
1959-1965	1.97	3.66	1.55	3.04	.42	.62
1966-1973	.27	2.35	.39	.31	-.12	2.04
1974-1977	-1.39	3.29	-.90	-.04	-.49	3.33

CHANGE IN LABOR DEMAND OVER TIME

The completion of econometric estimation for all five industries allows for the direct calculation of how changes in input prices, output, and technology affect employment. We measure the effect on labor in each year arising from a change in some exogenous variable like technology, when other exogenous variables were being held constant. The sum of the partial effects approximates the total change in labor for that year. The estimated results for both industries are averaged over time and presented in table 5. To illustrate their interpretation in the time trend version of steel, production worker man-hours would have declined about 2.05 percent a year because of increases in the wage (holding other input prices, output, and time constant).

The results for steel are practically insensitive to the measure used to represent technology. In both cases, advances in technology led to an average rate of decline in labor demand of about 1.70 percent per year. While this may seem large, it was less important than increases in workers' wages (regardless of how technology was measured). On the other hand, demand for production workers was increased by increases in the wages of nonproduction workers (since production and nonproduction workers are highly substitutable) and by increases in output.

In both industries, a change in the price of capital, fuel, or materials, holding other things constant, would only marginally affect employment although the sum of the three effects increased it.

TABLE 5

AVERAGE CHANGE IN PRODUCTION WORKER MAN-HOURS

Industry (Measure of Technology)	P_L	P_N	P_K	P_F	P_M	Q	T	Total (= $\sum$)
Steel (Time Trend)	-.0205	.0115	.0029	.0004	.0054	.0156	-.0172	-.0019
Steel (Direct Measure)	-.0177	.0139	.0028	-.0002	.0032	.0156	-.0166	.0010
Autos (Time Trend)	-.0112	.0155	-.0061	.0008	.0017	.0585	-.0370	.0221
Autos (Direct Measure)	-.0306	.0129	.0088	.0017	.0094	.0387	-.0126	.0248

Because the parameter estimates are different, the two measures of technology give different results for the auto industry. The implications and directions of effect are the same, however, even if magnitudes differ. First, for the time trend, the own price effect causes a decline in employment of about 1.1 percent a year; changing technology leads to an even greater decline of close to 4 percent a year. Overall, however, employment increases on average almost 2-1/4 percent, because of output changes and increases in the wage of nonproduction workers.

When the direct measure of technology is used, labor's own wage has a larger effect than in the time trend case--about negative 3 percent. Advances in technology still have a negative effect, but the effect is about one-third the size as when the time trend was used. The total effect of these two variables on labor is about the same for both the time trend and the direct measure. Changes in output and nonproduction worker wages are still most important in increasing employment, although the total is now slightly less than the time trend results. A further difference is that the effect of changes in capital's price is now positive, reflecting the estimated substitutability between labor and capital; in the time trend regression, labor and capital were found to be slightly complementary. The effect is small, however, and it is more likely that capital and labor are used in roughly fixed proportions in the short run (i.e., for fixed technology).

THE TOTAL EFFECTS OF TECHNOLOGY ON LABOR

We stated at the outset that technical change reduces the total amount of inputs needed to produce a given level of output, but by shifting the supply curve downward, it may, in balance, lead to an increase in employment.* The final level of labor demand depends upon which of the two effects of technology (i.e., substitution away from labor versus greater demand for labor to produce more output) is larger.**

To measure this second effect, we use some of the findings reported above in a simple model that relates output changes to changes in industry technology. We assume there exists a domestic product, Q, and a competing import, M. They are not perfect substitutes in use and some finite elasticity of substitution σ exists that measures how relative demands depend upon their relative prices. Changes in industry technology can affect domestic output prices though we assume that import prices are exogenous to our model.***

* The downward shift in supply means we move along the demand curve. This implies that the demand elasticity will be of crucial importance in the calculation.

** There is, in fact, another possible effect. Positive rates of technical change in one industry may also lead to lower costs and higher output in a second industry. Technical change in an industry whose products are used as material inputs in another (e.g., steel in auto production) may lead to lower prices in both, causing output and employment to rise in both. The computation of this effect for the second industry would be given by $\varepsilon_{LM} * V_{Mj} * d\ln P_{Mj}/dT$ where V_{Mj} is the share of input j in total materials cost and P_{Mj} is its price. This effect seems extremely small, and we ignore it in the following calculations.

*** Since this type of model is dependent upon information that is outside the scope of our econometric work, we draw upon estimates of the relevant parameters from the economic literature.

The Model

We begin, as before, with the cost function. Now, however, we are interested in changes in cost arising from new technologies. Since input prices are not dependent upon technology, changes in the logarithm of cost may be written as follows:

$$\frac{d\ln C}{dT} = V_Q \frac{d\ln Q}{dT} - V_T \ . \tag{13}$$

Output in the domestic industry is dependent upon its own price P_Q and other exogenous factors X. This is given by the relationship

$$Q = Q(P_Q, X) \ . \tag{14}$$

We assume P_Q is dependent upon industry technology but that X is not. From the functional relationship in (14), we obtain the following equation:

$$\frac{d\ln Q}{dT} = -\eta \frac{d\ln P_Q}{dT} \ . \tag{15}$$

The parameter η represents the elasticity of demand of domestic output Q. In turn, η can be shown (see Armington [2] for one derivation) to be dependent upon the elasticity of substitution σ and the elasticity of demand ξ of the aggregate product Y. Formally, the value for η is given by:

$$\eta = \left(\sigma S_M + \xi(1 - S_M)\right) \tag{16}$$

where S_M = share of imports in total demand and $-\xi$ = elasticity of demand for the aggregate product Y.

We continue to assume that $P_Q = C/Q$, which means that domestic price is equal to average cost. The percentage change in price due to changes in technology is given by:

$$\frac{d\ln P_Q}{dT} = \frac{d\ln C}{dT} - \frac{d\ln Q}{dT} . \tag{17}$$

Substituting for $d\ln C/dT$ from equation (15) and rearranging yields

$$\begin{aligned} \frac{d\ln P_Q}{dT} &= (V_Q - 1)\frac{d\ln Q}{dT} - V_T \\ &= -\frac{d\ln V_G}{dT} . \end{aligned} \tag{18}$$

Equation (18) says that the change in price is equal to the negative of the change in industry productivity. If productivity were to increase by say, one percent, there would be a fall in the price of industry output of one percent.

We now substitute back in equation (15), which relates output and price changes. Using equations (15), (17), and (13), and then solving for $d\ln Q/dT$, we obtain

$$\frac{d\ln Q}{dT} = \frac{\eta V_T}{1 - \eta(1 - V_Q)} . \tag{19}$$

Equation (19) relates the percentage change in output arising from a change in technology to the industry's elasticity of demand, rate of technical change, and degree of scale economies. This growth rate depends positively on the demand elasticity and technical change. If $V_Q = 1$, that is, the industry is characterized by constant returns to scale, then $d\ln Q/dT = \eta V_T$. If V_Q is less than one, then movements toward constant returns (i.e., $V_Q \to 1$), lead to a slower response in output changes from increases or improvements in technology.

To relate equation (19) to the labor input, we follow the same procedure described above to derive an expression for $d\ln L/dT$:

$$\frac{d\ln L}{dT} = \left(\frac{\gamma_{LQ}}{V_L} + V_Q\right) \frac{\eta V_T}{1 - \eta(1 - V_Q)} + \frac{\gamma_{LT}}{V_L} - V_T . \tag{20}$$

The output effect of technology is given by the first term on the right-hand side of (20). If there is a technical change, price will fall, and output and employment will rise. The second term, which was discussed earlier, represents the partial effect of technology.

Results

Table 6 presents the average values of the the output, partial, and total effect of technology over the 1959-1977 period.* For steel, the output effect is negligible regardless of how technology is measured. This is due to the (almost) zero rate of technical change in steel. Employment is reduced by just over 1.8 percent a year.

TABLE 6

THE EFFECTS OF TECHNOLOGY ON LABOR[a]
(All Industries)

Industry (Measure of Technology)	Output effect	Partial effect	Total effect
Steel (Time Trend)	-.0014	-.0172	-.0186
Steel (Direct Measure)	-.0017	-.0166	-.0183
Autos (Time Trend)	.0234	-.0370	-.0136
Autos (Direct Measure)	.0135	-.0126	.0009

[a]For values of S_M, σ, and ξ, we relied on [16] for steel and [29] for autos. The values used for σ and ξ as well as the mean value of S_M are provided below:

Steel: $\sigma = 5.9$, $\xi = .34$, $\bar{S}_M = .12$

Autos: $\sigma = 2$, $\xi = 1$, $\bar{S}_M = .12$.

For autos, the output effect is important and differs slightly in magnitude depending on which measure of technology is used. The output

* In reporting results, we really calculate the value $\frac{d\ln L}{dT}\frac{dT}{dt}$. This is needed when T represents the direct measure in order to make the units correspond to per year values.

effect is almost twice as large with the time trend as in the direct measure case (a result of a larger ε_{LQ} and V_T and lower V_Q). The partial effect, on the other hand, is about three times as large and so the total effect remains negative. The direct measure results illustrate how the output effect may be even larger than the partial effect and so, the net effect of technology becomes slightly positive.

CONCLUDING REMARKS

Technical change has two effects on employment, the partial or substitution effect and the indirect or output effect. Much of this paper has dealt with obtaining better estimates of the substitution effect, i.e., the employment change due to new technologies when output is held constant, by use of an econometric model. An important consideration in developing the model was that it allowed us to distinguish the effects of technical change from scale economies.

The substitution effect was negative in both steel and auto industries, regardless of the measure of technology. The effect was stronger in the auto industry, which experienced substantial, and growing, technical change over the period. Steel, with virtually no technical change, still experienced labor displacement due to new technology, but this apparently was solely the result of the installation of less labor intensive production processes.

We also compared the results and the implications for employment demand when alternative measures of technology (the time trend and a measure of new process innovation) were used in our models. In general, the way in which we measured technology did not affect the results very much; the conclusions were substantively the same. Economists typically measure technology with a time trend; our results indicate this may be a reasonable simplification.

The degree of labor displacement is potentially lessened by the output effect of new technology. Changing or new technologies may lead to lower output prices and increases in output demanded. This leads, in turn, to increases in employment. Though insignificant for steel (since technical change was near zero), we found that, for autos, the output effect led to growth in output and therefore employment growth that counterbalanced some of technical change's labor-saving characteristics. The overall decline in employment due to technology, once both the output and substitution effect are accounted for was relatively small and did not typically move in great jumps from year to year. Rates of normal labor turnover, i.e., turnover due to retirements and quits, are usually higher and could handle the declines in employment caused by changing technology.

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